Similar comparative observations have been made on the fresh water mussel and the oyster. Even detached portions of the frog have been found to move, and it will be a genuine surprise to physiologists to learn, that the heart of the frog, so long and so much investigated, has likewise a wonderful power hitherto unnoticed, that of travelling about when detached from the body, having covered a distance of half-an-inch in 10 minutes. These and other matters will, however, require separate treatment.

ART. XIV.—*Rainfall and Flood Discharge.*

BY G. R. B. STEANE.

[Read November 5, 1887.]

The subject of maximum Flood Discharge is one of considerable importance to the engineering profession, particularly to those upon whom falls the responsibility of constructing drainage outlets, culverts, bridges, &c. Though the subject has been practised for thousands of years and there have been millions of opportunities for observation, the bulk of the opportunities have been lost, owing to the fact that the surrounding circumstances have not been observed, and the information has not been published.

A few engineers have paid attention to the matter of river discharge and published the information, but on the whole, I think, the subject has been neglected. I know of very many instances where costly works have been constructed to answer certain purposes and have failed, causing damage to many times the value of a proper structure. As an evidence of the difference of opinion held by authorities, I cannot refrain from referring to evidence given at an enquiry held on the Cootamundra disaster, where five engineers gave different opinions—one said the culvert was not sufficient to take $\frac{1}{3}$ inch of rain in 24 hours, and another said it would take 28 inches of rain in 24 hours. Matters being thus, I need no other excuse for referring to this subject.

Mr. Beardmore, in his Manual of Hydrology, has devoted a section to discharge from rivers, and gives a list from many sources. Mr. L. de A. Jackson in his Hydraulic Manual, devotes a space to it. Mr. Neville in his work also devotes a space to it.

As a preliminary to the subject, I submitted a paper to this Society, Notes on Hydrology, in June 1883. In June 1885, in Section A, I also submitted a paper on Rainfall and Flood Discharge, and with the hope of preparing a paper worthy of submitting here, I posted more than 150 circulars to engineers, but failed to elicit any data. I have, therefore, to submit this paper, bald as it is, with the hope that other information may be supplied by those who may have had better opportunities for observing. I claim a little indulgence for introducing matters of an elementary character with the data I submit.

The amount of discharge depends on many circumstances. The amout of rain ; size of area, especially the nature of the area varying from rock to beds of sand ; the form of the area ; inclination of surface, whether dry or soaked. I propose only to deal with the maximum discharge, and that due to the rainfall only ; the maximum discharge depends on the maximum rainfall.

The rainfall has been observed as to the total daily fall in many places, but the same attention has not been paid to the amount in times of short duration (B), and the area over which that rain falls. We have records such as an inch in fifteen minutes, but no evidence of the extent of such rains. The maximum discharge must take place from any watershed, when with the maximum rainfall over the whole area, it has continued long enough for a drop from the extreme distance to join drops from the whole of the area at the outlet. Hence the time the water takes to travel the longest distance must be an element in the discharge, and we must approximate the rain which falls in that time. Supposing it to be such a length as to take an hour to travel, we must approximate the rain—suppose it an inch.

The next, and a difficult and serious matter in the estimate, is the soakage. During the average time that the discharge at any instant has been travelling, soakage has been taking place, and the amount of soakage varies much more than the rain. I have no doubt that parts of sandy areas, such as Caulfield and Brighton, will absorb water faster than any rain that ever fell.

For the purpose of arriving at the form a simple formula should take, it appears to me to be necessary to assume quantities which cannot be fixed. The rainfall, for instance, I assume to vary as the cube root of the time:—1 inch in ¼ hour, 2 inches in 2 hours, 4 inches in 16 hours, 8 inches in 5½ days. The observed quantities I give at the end (A). If the total maximum rain be assumed to vary as $\text{time}^{\frac{1}{3}}$, the rate of fall will vary as $\frac{\text{time}^{\frac{1}{3}}}{\text{time}} = \frac{1}{\text{time}^{\frac{2}{3}}}$ Assume the watershed a constant narrow width, and assume the water to flow at a constant rate, which though not true, the tendency is to equalise, as the grades near the extreme limits are generally steeper. The area will vary as the time the water has to travel, and the discharge will vary as $\frac{\text{area}}{\text{time}^{\frac{2}{3}}} = \frac{\text{area}}{\text{length}^{\frac{2}{3}}}$

Then, if we assume length to vary as $\sqrt{\text{area}}$, $l = a^{\frac{1}{2}}$, as for similar figures and substitute we obtain discharge varies as $\text{area}^{\frac{2}{3}}$. This takes no account of soakage, or varying inclinations.

That is, that the maximum discharge will depend on the area, and inversely on some power of the length, and this is the form that I have adopted.

For small areas of clay and rock, and tolerably impervious surfaces in larger areas, I have for the present adopted the following in the same form:—

$$\text{Discharge cubic feet per second} = \frac{\text{area sq. chains} \times 181}{\text{length chains}^{1 \cdot 23} + 1800}$$

The co-efficients for which I have obtained from the following three recorded observations:—

Maximum discharge 4 feet per second from 4 acres, length 7 chains.

Bendigo Creek 4100 feet per second from 10,000 acres, length 7½ miles.

Coliban 10,000 feet per second from 64,000 acres, length 22 miles.

The first two are my own, the last was obtained from a report on the Coliban works, which also mentioned a reported discharge of 32,132, but this I think doubtful. I should like, if I could obtain the necessary data, to obtain co-efficients for various average character of watersheds. I need hardly remark that this formula would be inapplicable for very absorbent ground or sandy areas.

We may also estimate the discharge in a more direct manner.

Let $Rt^{\frac{1}{3}}$ = rainfall for any period, $\frac{R}{t^{\frac{2}{3}}}$ = rate of fall, for instance so many inches per hour, where t is the time the water takes to travel the length of the watershed. If we put S for hourly soakage, as it will take less than t for the average time for the whole of the water to reach the outlet, it may be t^x or $\frac{t}{x}$, and knowing that 1 inch rain per hour represents very nearly a discharge of 1 foot per second per acre, we arrive at the following:—

$$\underset{\text{area}}{(\text{acres})}\left(\frac{R}{t^{\frac{2}{3}}} - \frac{t}{x}\,s\right) = \text{discharge per second.}$$

As time and the length depend on each other, substitute $\frac{l}{v} = t$, we obtain

$$a\left(\frac{R}{\left(\frac{l}{v}\right)^{\frac{2}{3}}} - \frac{l}{vx}\,s\right) = \text{discharge.}$$

Again, assuming s v x to be constants, we obtain

$$a\left(\frac{x}{l^{\frac{2}{3}}} - ly\right) \text{ or } a\left(\frac{x}{l^{x}} - ly\right)$$

Which corresponds very nearly with Mr. Burge's No. 3

$$a\left(\frac{x}{l^{\frac{2}{3}}}\right)$$

The effect of soakage being omitted, hence I have adopted

$$\text{discharge} = a\,\frac{181}{l^{1 \cdot 23} + 1800} \quad a \text{ and } l \text{ in chains.}$$

The objection to this formula is, that when applied to very large areas and long rivers, the high power of the length reduces the quantity too rapidly; I would therefore alter a and l to miles, and adopt different co-efficients.

The following formulæ are given in Mr. Jackson's "Hydraulic Manual:—"

1st. $Q = k_1\ 27\ (K)^{\frac{1}{2}}$
2nd. $Q = k_2\ 100\ (K)^{\frac{3}{4}}$
3rd. $Q = k_3\ 1300\ K\ (L)^{-\frac{2}{3}}$

$Q =$ discharge cubic feet per second; K area square miles; L length miles; and $k_1\ k_2\ k_3$ local co-efficients.

The first is most simple, but k varies so much as to make it inconvenient, and no attention is paid to the shape.

The second is a modification of Col. Dickens' formula, which was suited to Bengal, but $k \propto$ 1 to 24.

The third was deduced by Mr. Burge, of Madras.

4th. Mr. Jackson proposes $Q = k_4 \frac{B}{L}\ 100\ (K)^{\frac{3}{4}}$

I don't know the object of a numerical constant and a variable constant. (?)

5th. Mr. Hawkesley, an eminent authority, supplies a formula for the diameter of outlet pipes log. dia. inches =

$$\frac{3 \text{ log. area acres} + \text{log. length, in which sewer falls 1 ft.} + 6{\cdot}8.}{10}$$

by using Mr. Hawkesley's formula for discharge $D = C\ \sqrt[5]{\frac{G^2 L}{H}}$, it is easily proved that the formula 5 is constructed on the assumption that the discharge varies as $K^{\frac{3}{4}}$ without regard to form.

6th. Mr. B. Zeigler, of Zurich, supplies the following formula $R = r \times c\ \sqrt[4]{\frac{s}{a}}$

r being average rain, $C =$ coef., varying from ·75 for cities and ·31 for suburbs, $s =$ fall in area or grade per 1000, and $a =$ area drained, giving R resultant rain discharge, and this I find to vary as $S^{\frac{1}{4}} K^{\frac{3}{4}}$, but by this if $\frac{s}{a}$ under the sign becomes greater than 1, the result is incorrect. Three inches of rain with grade $\frac{8}{1000}$ and $\frac{1}{4}$ acre will give a rain discharge of 5·3 inches, evidently wrong for small areas.

Transactions of the Institute of C.E. England, 1883, on Improvement of River Broye. Mr. Gangnillet gives the form as

$$\text{discharge} = c \times \sqrt[b]{K} \text{ for floods}$$

and the maximum discharge is said to vary as a curve of an equilateral hyperbola.

Lieutenant P. P. L. O'Connell, Associate of Institute of C.E., in January 1868, argued that the maximum discharge from similar water-sheds varied as the curve of a common parabola.

On the whole, I think it may be agreed that a simple formula can only be a rough approximation.

For tolerably impervious surfaces, such as clay, a useful simple approximate formula for the sectional area of a waterway, is the following :—

$$\text{area of culvert in square feet} = (\text{area in acres})^{\cdot 62}$$

only a rough approximation.

In conclusion, I supply a few facts which have come under my own observation, a list kindly supplied by Mr. Gordon, and also a list that I have acquired from time to time from various sources. I would also direct attention to a list in Mr. Beardmore's Hydrology, and pages 94 and 95, Vol. XX. Transactions of the Victorian Royal Society 1883; and hope that some experienced in Hydrology may supply information at some future date on this, to me, interesting subject.

Some years ago, a borough was founded with a creek through its centre. It was found to be a considerable detriment. The local Council decided that it would be advisable to remove two bridges and cover over a considerable part of this creek. Their surveyor prepared a design with about 190 feet area waterway for 10,000 acres, and application was made for a Government grant; the grant was allowed subject to approval of the Government Engineers. The Government Engineers reported that the waterway was excessive, and recommended that it should be reduced by $\frac{1}{3}$. That surveyor was an obstinate man and would not cede the third. Ultimately, the plan was approved and the creek was covered, and I have seen floods over that many times a year. I pulled that culvert up and put down a new one 370 feet area. Since the time I refer to, a culvert was put down at Cootamundra, with a water-shed of somewhat similar character, but 13,000 acres instead of 10,000, with a sectional area of 52 feet. The result known, a flood—verdict, abnormal flood.

(a.)

HEAVY RAIN STORMS.

DURATION.	RATE PER HOUR.	LOCALITY.	DATE.
2 min.	6· in.	Sandhurst	28/11/82
4 ,,	5· ,,	,,	,,
15 ,,	4· ,,	Melbourne	10/3/77
20 ,,	5·4 ,, (?)	Ballarat	—/3/76
30 ,,	2·4 ,,	,,	2/3/64
75 ,,	2·0 ,,	Sandhurst	11/2/77
90 ,,	·75 ,,	..	..
24 hours	·15 ,,	Sandhurst	16/3/78
30 ,,	·2 ,, (?)	Beechworth	31/8/75
48 ,,	·10 ,,	Sandhurst	15-16/3/78
30 ,,	·19 ,,	Gordons	6/1/87
6½ ,,	·28 ,,	Ballarat	6/1/86
12 ,,	·19 ,,	Melbourne	6/1/86

(b.)

At Ontario, 10th July, 1883, 4 in. of rain fell, and extended over an area 50 miles by 20 miles. Eliptical in form.

Prof. F. E. Niphe (*Science*, p. 409, 1884), says from 47 years' observations, at St. Louis, he arrived at the conclusion that the duration of a rain was inversely proportional to the violence.

Sir J. W. Bazelgate (Journal, Franklyn Institute, 1882), says 2·64 in. rain fell in 19 hours over the whole of the London Metropolitan District.

AUTHORITY.	WATERSHED.	DR'NAGE AREA. SQ. MLS.	DISCH. CUBIC FT. PER MIN. PER SQ. M.	REMARKS.	TOTAL DISCH'GE CUBIC FT. PER SEC.	APPROX. LENGTH. MILES.	DISCH'GE FROM MY FORM'LA.
Mr. G. Gordon, C.E.	Goulburn	3155	906	Murchison, 1870	47640	112	49070
,, ,,	Moorabool	1623	2957	Flood, 1852	79986	50	65398
,, ,,	Yarra	1546	2102	Flood, 1863	54161	85	33438
,, ,,	Campaspe	1088	3355	Axedale, 1870	60838	50	43841
,, ,,	Wimmera	750	1154	Glenorchy, 1870	14425	50	30222
,, ,,	Coliban	100	7250	1870 (another doubtful, 17191)	12081	20	10791
,, ,,	Moonee Ponds	64	4688	Flood, 1880	5000	20	6906
,, ,,	Bullarook Creek	22	5137	Flood, 1870	1884	8	5500
(?) Steane	Yarra	1584	..	..	35000	80	36698
Steane	Campaspe	1088	..	Flood, 1870	54000	50	43841
Mr. Culcheth, C.E.	Barwon	1500	..	..	71000	80	34864
Steane	Bendigo Creek	15$\frac{2}{3}$	..	..	4100	7½	4100
Reports	Coliban	100	..	..	10000	20	10790
Mr. J. K. Smith, C.E.	Elizabeth-st. City of Melb'rne	·776	..	..	410	1·25	430
Mr. Thos. Haynes, C.E.	Reilly-st. Drain	2·87	..	..	1118	2·50	1342

LIST OF SECTIONAL AREAS OF OUTLETS, BRIDGES, &C.

AREAS OF WATERSHEDS, &C.

LOCALITY.	AREA—ACRES.	SECTION.	REMARKS.
Maher's Bridge, Bendigo Creek	14,500	Bridge, 230 ft.	Flooded.
Back Creek Bridge, Sandhurst	2,700	,, 103 ft.	Often flooded.
Golden Gully ,,	600	Culvert, 33 ft.	Bad inlet, often flooded.
Cricket Ground ,,	230	,, 19·3 ft.	Too small
,, ,, ,,	230	,, 25 ft.	A new one lower down—enough.
Adelaide Gully ,,	280	,, 23 ft.	Flooded, but rarely.
Hargreaves Street ,,	65	,, 12 ft. to 13 ft.	,, ,, ,, a long Culvert.
Barkley Street ,,	8	Channel, $2\frac{1}{4}$ ft.	Great fall—filled.
Long Gully ,,	1,200	Bridge, 66 ft.	Overflowed.
New Chum ,,	205	Bridge, 28 ft.	Never flooded.
Vine Street ,,	48	Culvert, 5 ft.	Often too small.
Dowling Street ,,	112	Culvert, 20 ft.	Good fall. Filled, but not over.
Bye Wash Park ,,	112	Footbridge, 22 ft.	Overflowed. Bye wash bridged over.
,, ,, ,, ,,	85	,, $15\frac{1}{2}$ ft.	Overflowed slightly.
Plenty River	38,400	440 ft.	Overflowed. Mr. Taylor authority.
Spencer Street, Melbourne	98	Culvert, 8·3 ft	A. K. Smith. Length 58 chains Enough to date, 1864.
Thomas Street, Sandhurst	3·7	Culvert, 1·2 ft	A box 25 ft. long 20 in. x $8\frac{1}{2}$ in. Good outlet. Sometimes small.

LIST OF SECTIONAL AREAS OF OUTLETS.

AREAS OF WATERSHEDS AND ESTIMATED DISCHARGES, &C.

LOCALITY.	AREA—ACRES.	SECTION.	ESTIMATED DISCHARGE, FT. PER S'COND	ESTIMATED DISCHARGE FT. PER S'COND PER ACRE.	REMARKS.
Pakington Street, St. Kilda -	12	15 in. pipe	7	·60	Long pipe. Several ft. head. Too small.
Charles Street ,, -	20½	15 in. ,,	11½	·51	Level crossing. Good fall. Too small.
Wellington Street ,, -	15	15 in. ,,	10·3	·68	,, ,, Rarely small.
Chapel Street ,, -	500	Channel	50 at flood	·10	Sandy area a portion.
Argyle Street ,, -	62	5 ft. Culvert	25	·40	Flooded.
Chapel Street ,, -	67	17 in. pipe	17	·25	Short pipe, good head. Often small.
,, ,, ,, -	2000	42·4	300	·15	Filled, large area in Caulfield (Main drain).
Union Street ,, -	234	Channel	140	·60	
Westbury Street ,, -	50	5 ft. Culvert	40	·80	Not filled.
Swanston Street, Melbourne -	188	12·3 ,,	86	·46	Overflowed.
,, ,, ,,	188	14 ,,	98	·52	Never overflowed.
Elizabeth Street ,, -	497	Channel, &c.	410	·82	A. K. Smith authority.
Bourke and Russell Sts., Melb. -	10	15 in. pipe	11·5 including overflow.	1·14	23/12/85. Good fall. Good inlet and head. Too small.
Hargreaves Street, Sandhurst	65	13 ft. Culvert	65	1·00	Long culvert. Has overflowed.
Bendigo Creek ,,	10,000	297	4100	·41	Grade 1 in 220.
,, Myrtle St. Bridge ,,	9500 ?	266			Not overflowed.
,, Golden Sq. ,, ,,	9000 ?	245			Overflowed. Bad approach.
,, Booth St. ,, ,,	9000 ?	240			Overflowed a little.
,, Laurel St. ,, ,,	9000 ?	228			Overflowed.
,, Maple St. ,, ,,	9000 ?	288			Not overflowed.
,, Alder St. ,, ,,	7500 ?	220			Overflowed.